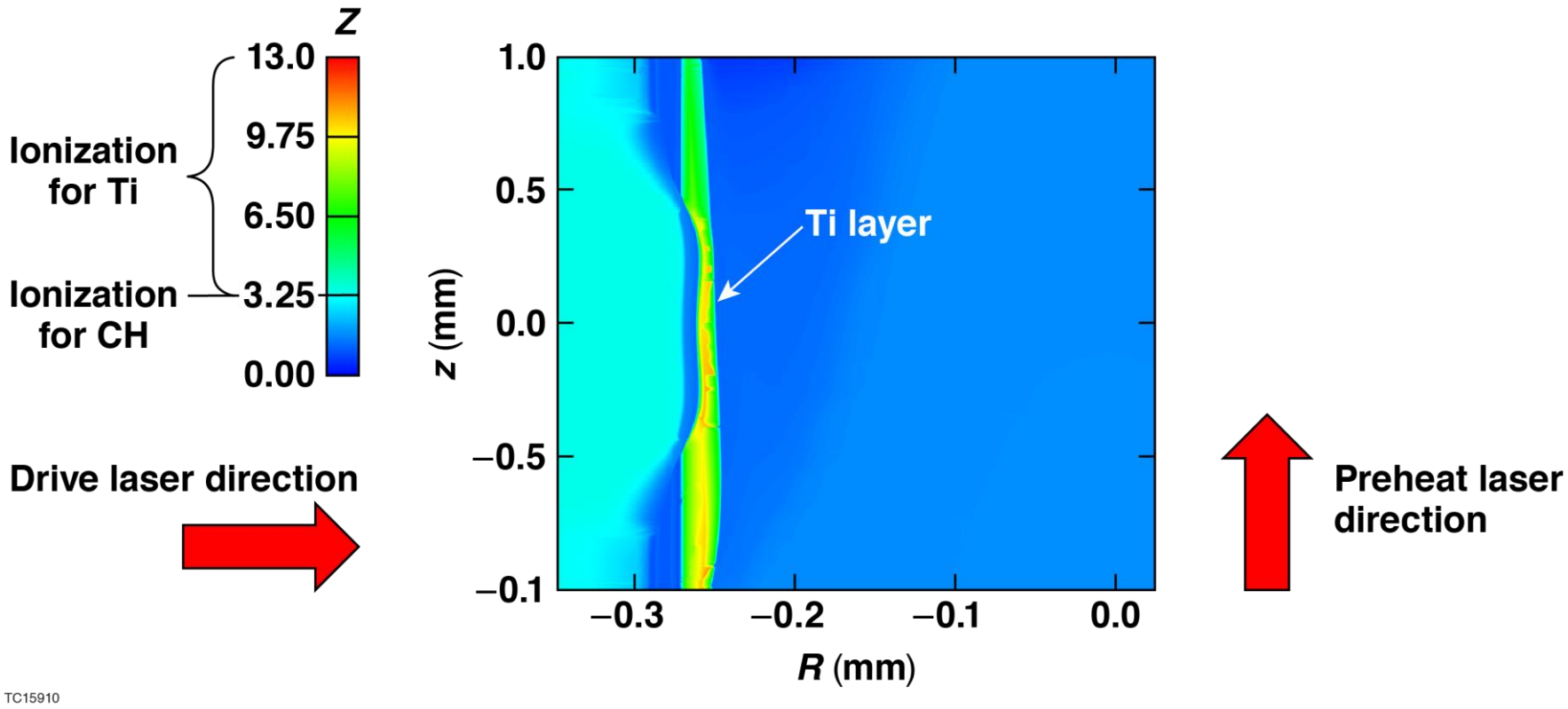
Simulations of Ti-Layered Magnetized Liner Inertial Fusion Implosions on OMEGA Investigating the Effect of Mix



L. S. Leal
University of Rochester
Laboratory for Laser Energetics

63rd Annual Meeting of the APS
Division of Plasma Physics
Pittsburgh, PA
8–12 November 2021

Summary

HYDRA simulations and experiments point to wall mixing as a neutron yield degradation mechanism in MagLIF on OMEGA

- In implosions without a Ti layer, inclusion of a premixed fuel region leads to better agreement between simulations and experimentally measured quantities
- In simulations with a Ti layer there is hydrodynamic expansion but little actual yield degradation
- Simulations with a Ti layer only showed neutron yield degradation comparable to experiments with a mixed fuel region (Ti in the fuel)

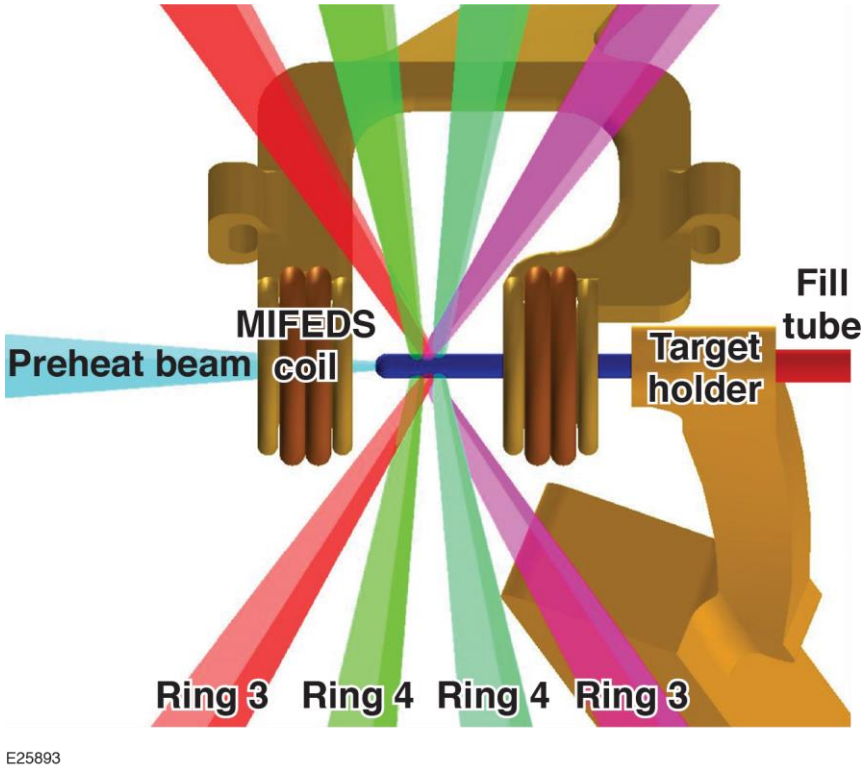
MagLIF: magnetized liner inertial fusion implosions

Collaborators

J. L. Peebles, D. H. Barnak, J. R. Davies, A. V. Maximov,
E. C. Hansen, P. V. Heuer, A. B. Sefkow, and R. Betti

University of Rochester
Laboratory for Laser Energetics

Mini-MagLIF is a magneto-inertial fusion concept at LLE that uses axial magnetic fields with laser-driven compression and preheat



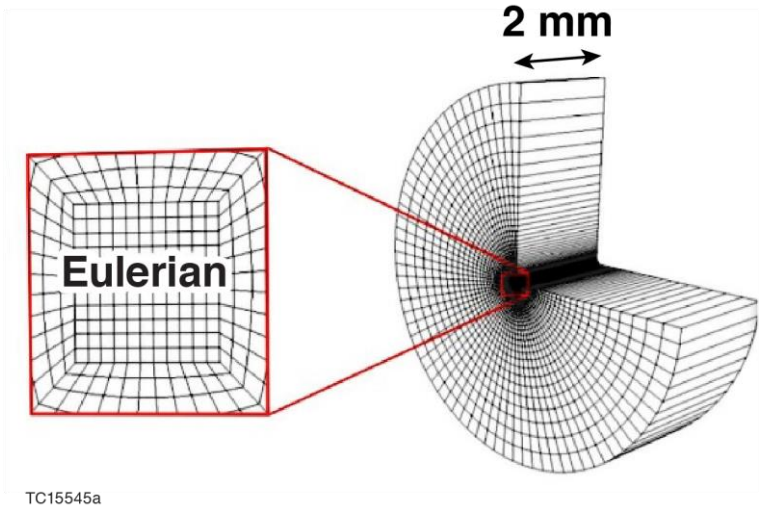
- Driver and preheat beams are 1.5-ns square-shaped pulses; the preheat laser begins 1 ns before the driver
- Beam radius of 200 to 300 μm, R_{beam} of the same order as R_{target}
- Preheat laser entrance window 1 mm from region of interest; experiments have seen no mix from window
- Smaller scale than Z at Sandia; thermal conduction from preheat hits the wall before any shock is formed

$$t_{thermal} \sim 1.6\left(\frac{2}{A}\right)\left(\frac{\rho}{2.4\ \mathrm{mg/cm^2}}\right)\left(\frac{T}{400\ \mathrm{eV}}\right)^{-5/2}\left(\frac{r}{0.3\ \mathrm{mm}}\right)^{2}\ \mathrm{ns}$$

$$t_{thermal,OMEGA} \sim 1 \text{ to } 3\ \mathrm{ns}, \qquad t_{thermal,Z} \sim 92\ \mathrm{ns}$$

J. R. Davies *et al.*, Phys. Plasmas 24, 062701 (2017).
J. L. Peebles *et al.*, CO05.00010, this conference.
MIFEDS: magneto-inertial fusion electrical discharge system

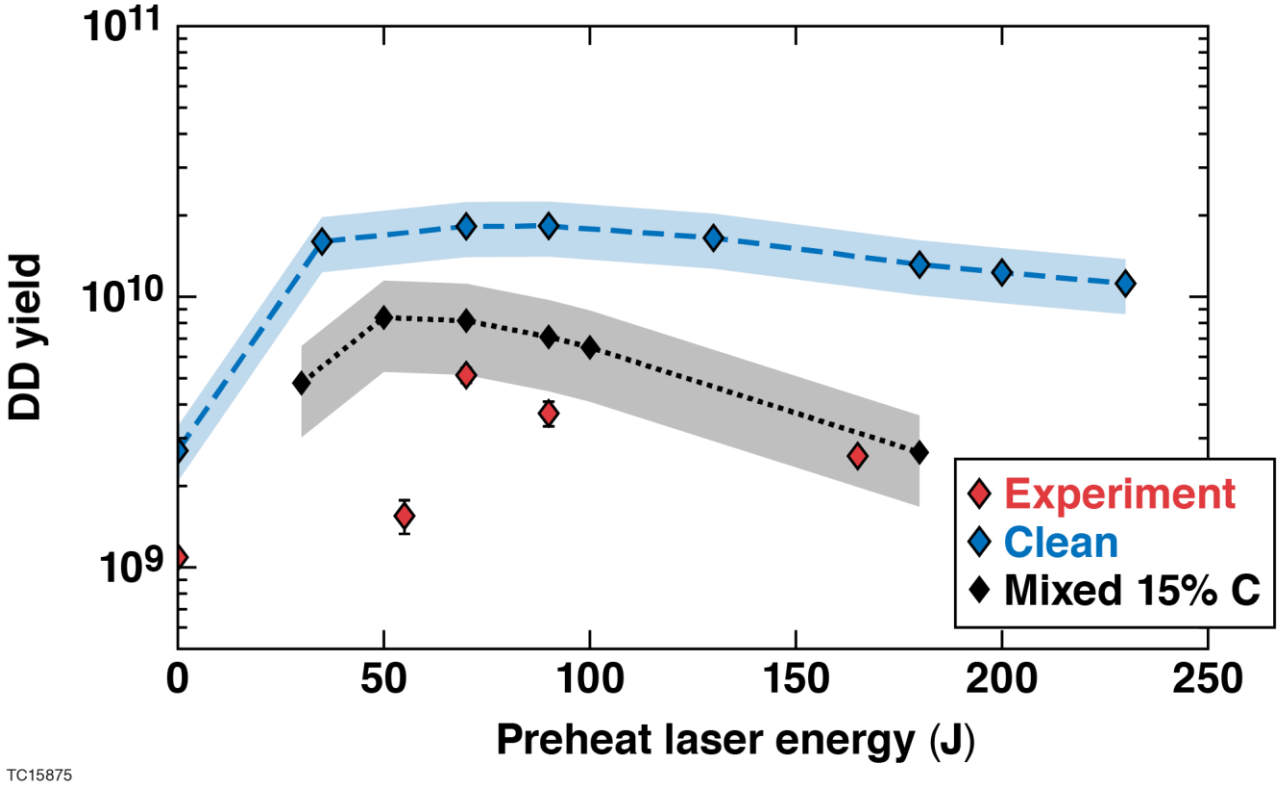
Three-dimensional *HYDRA* simulations are used to model mini-MagLIF experiments

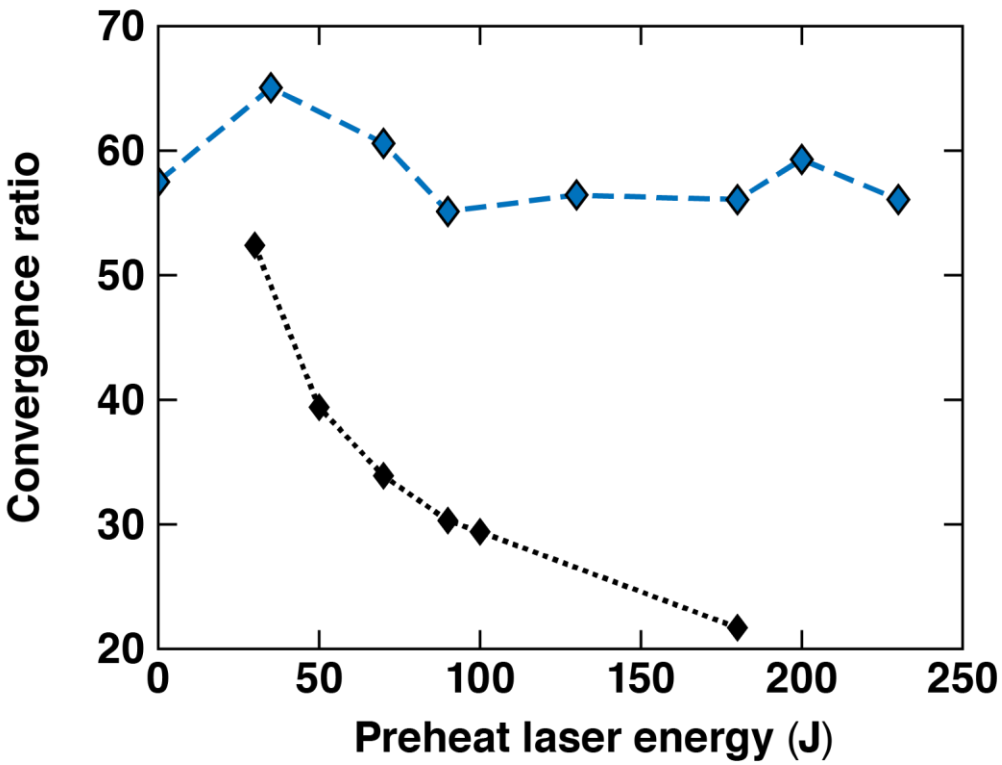


- Simulations use a magnetohydrodynamic (MHD) package including Nernst and Righi–Leduc terms in Ohm's Law and heat flux equation
- Direct-configuration accounting (DCA) atomics package is used to model mixed regions
- Ten radial zones are initially used to model a 0.2-μm Ti layer
- Butterfly mesh a employed during stagnation stages

E. C. Hansen *et al.*, Phys. Plasmas 27, 062703 (2020).
M. M. Marinak *et al.*, Phys. Plasmas 8, 2275 (2001).

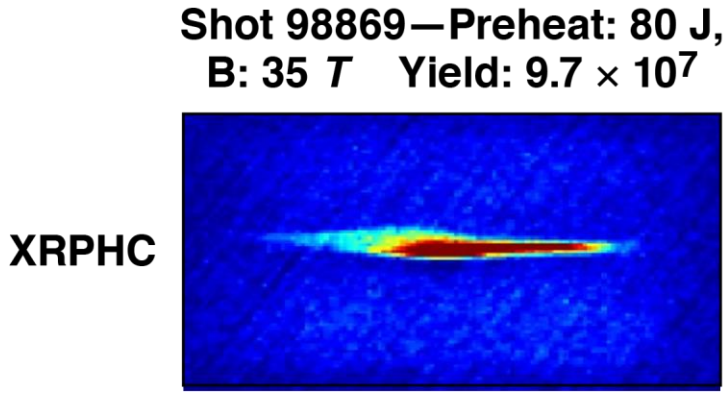
Simulations tend to overpredict neutron yield; including the premixed fuel region brings simulation results closer to experimental results



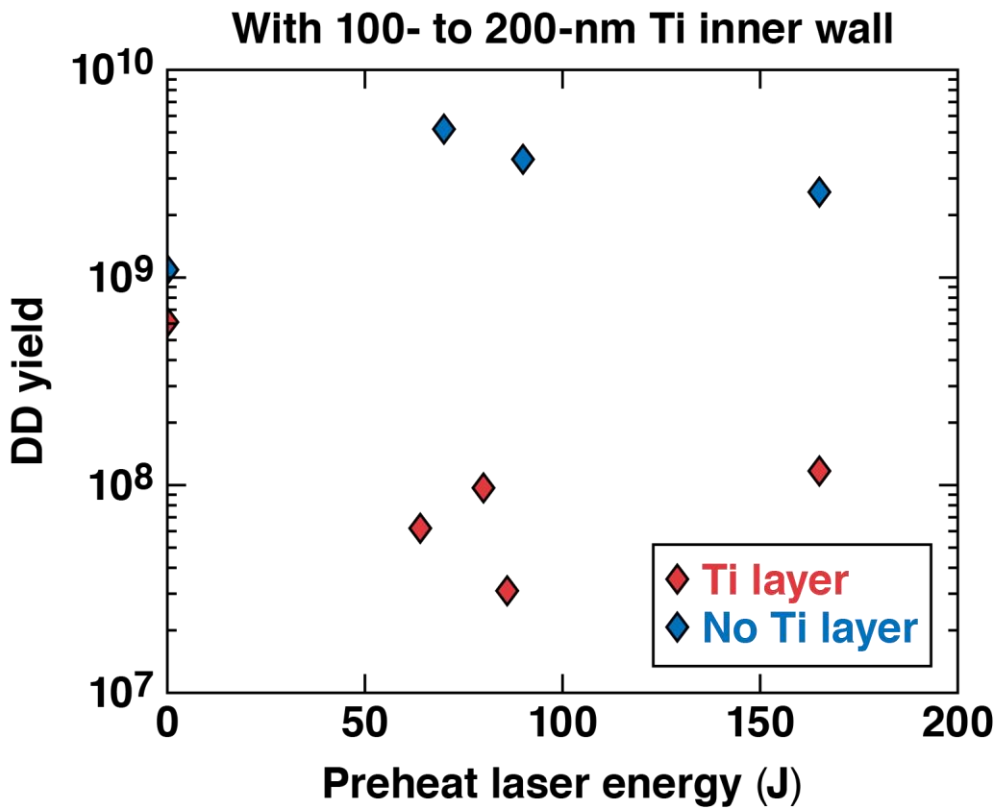


- 15% atomic carbon mix would amount to 200-nm thickness from wall
- Simulations with mix convergence ratio (CR) become sensitive to preheat energy

Experiments with a Ti inner wall showed large yield degradation and emission from the core in Fresnel zone plate (FZP) images

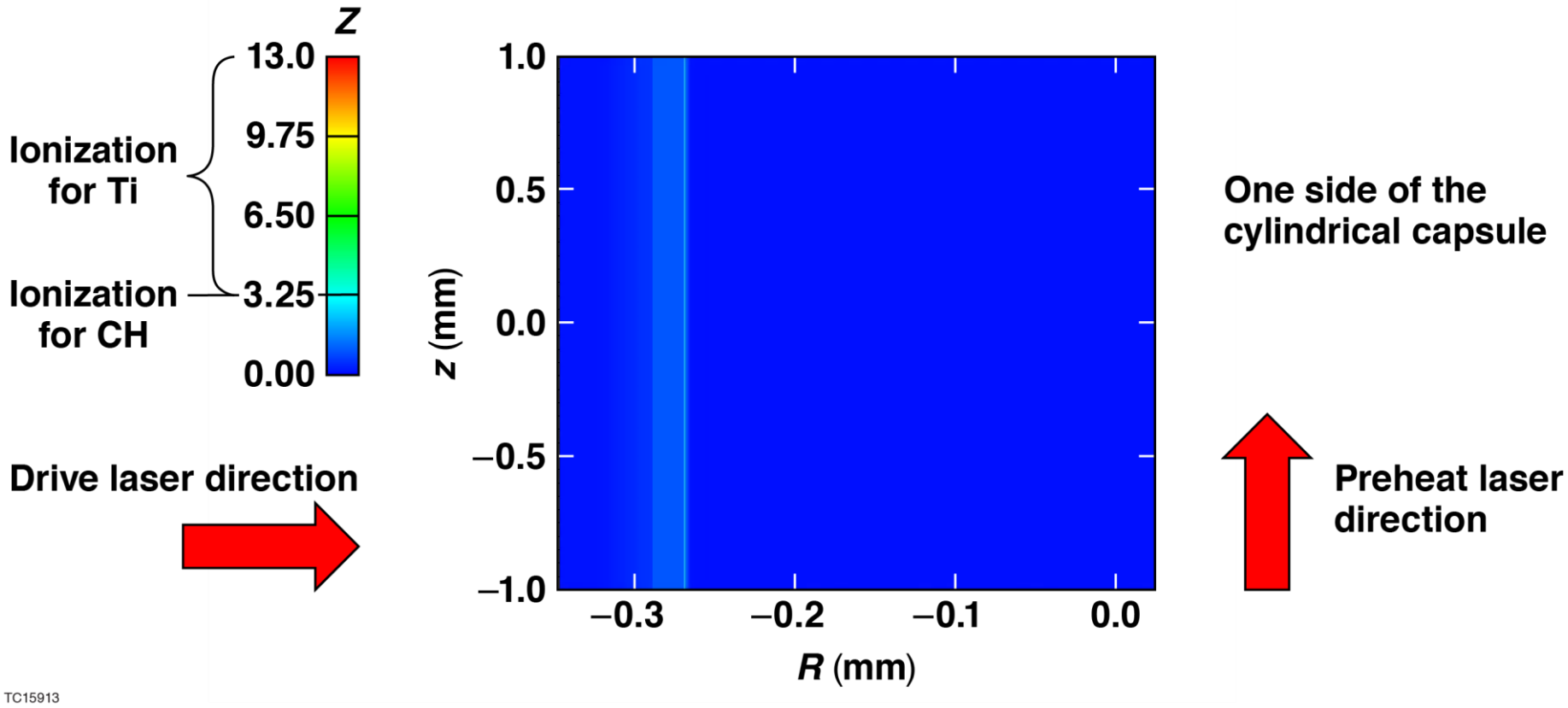


TC15912

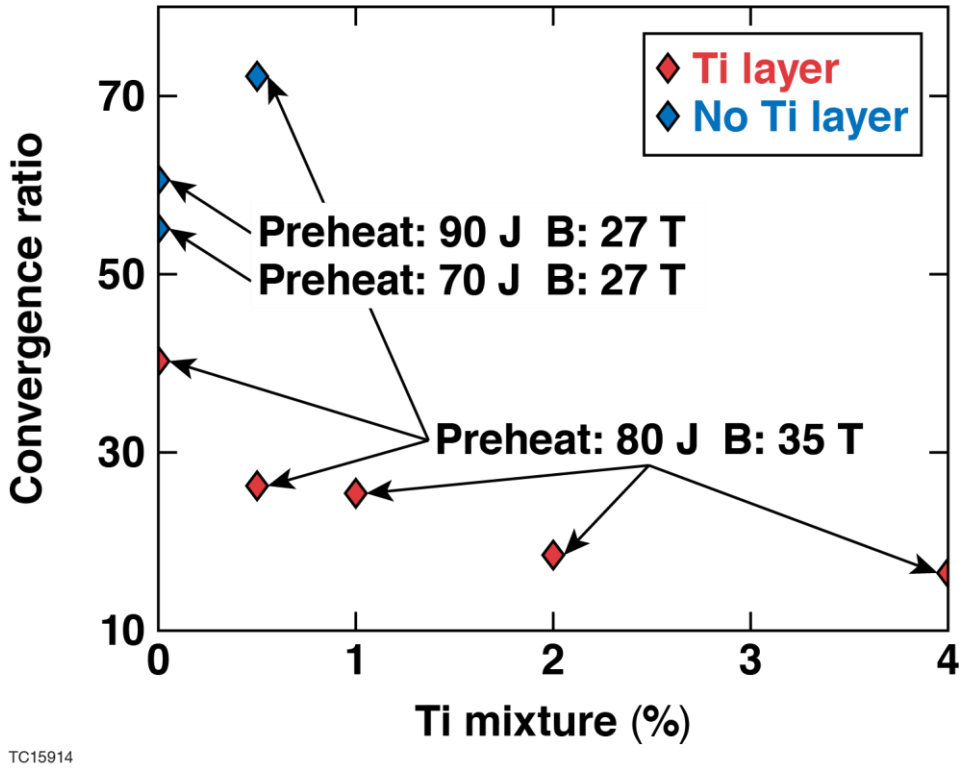


J. L. Peebles *et al.*, CO05.00010, this conference.
XRPHC: X-ray pinhole camera

The Ti layer expands hydrodynamically during preheat but is concentrated toward the edge during the implosion

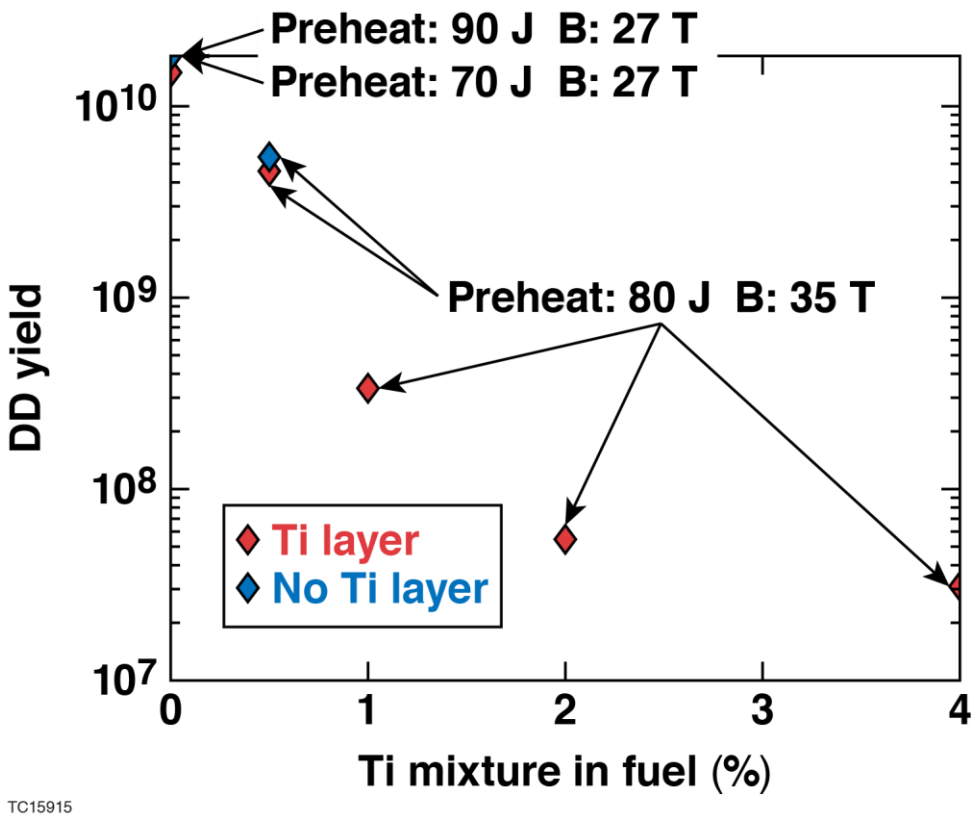


Simulations with a Ti layer have lower convergence ratios compared to those without



Adding/increasing mix percentage lowers convergence ratios in simulations with Ti wall

Simulations with the Ti wall show only 10% to 15% yield degradation; Ti in the core can lower yield by orders of magnitude



Preheat (J)	B (T)	Ti fuel mix %	0.2 μm Ti wall layer	Y_{DD}	Preheat T_i (eV)
70	27	0%	No	1.83×10^{10}	58
80	35	0%	Yes	1.50×10^{10}	66
80	35	0.5%	No	5.43×10^{9}	74
80	35	0.5%	Yes	4.58×10^{9}	72
80	35	4.0%	Yes	3.10×10^{7}	56

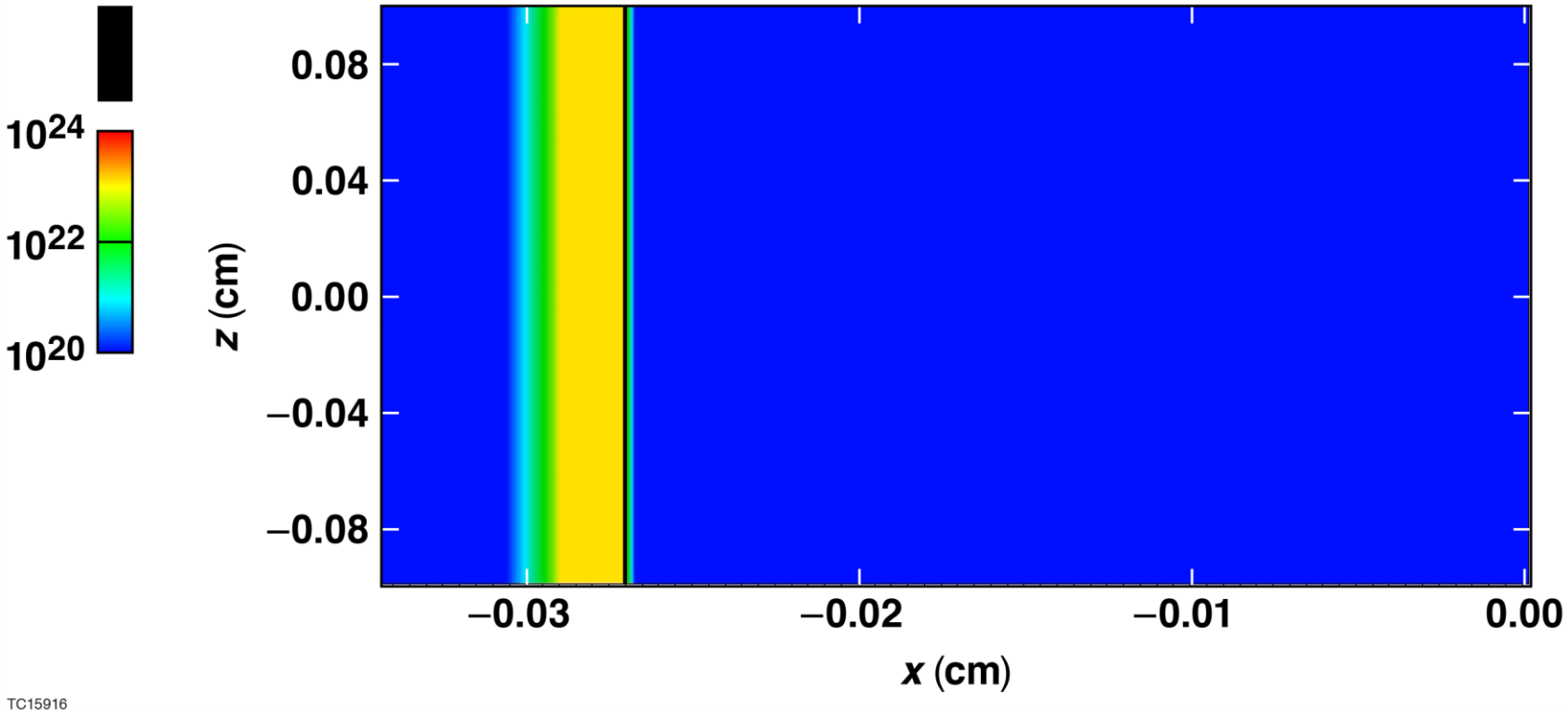
- The Ti wall layer alone drops the yield by 10% to 15%
- Much larger drops (two orders of magnitude) with large quantity of Ti mixed with fuel

Summary/Conclusions

HYDRA simulations and experiments point to wall mixing as a neutron yield degradation mechanism in MagLIF on OMEGA

- In implosions without a Ti layer, inclusion of a premixed fuel region leads to better agreement between simulations and experimentally measured quantities
- In simulations with a Ti layer there is hydrodynamic expansion but little actual yield degradation
- Simulations with a Ti layer only showed neutron yield degradation comparable to experiments with a mixed fuel region (Ti in the fuel)

Density with Ti borders

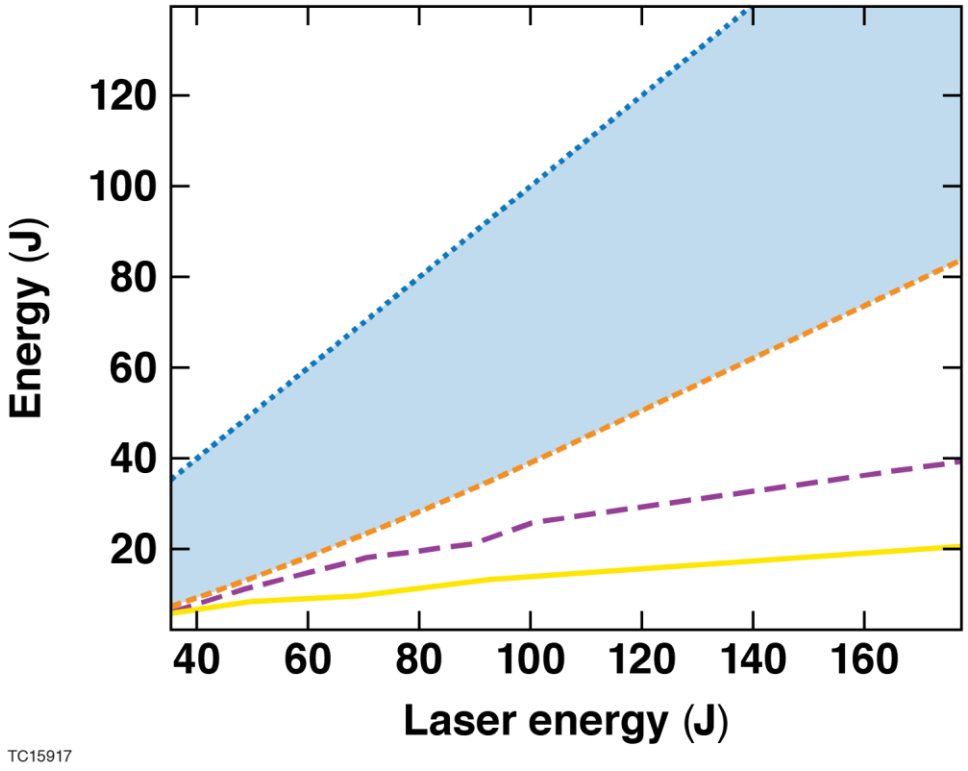


Simulations with the Ti wall show only 10% to 15% yield degradation; Ti in the core can lower yield by orders of magnitude

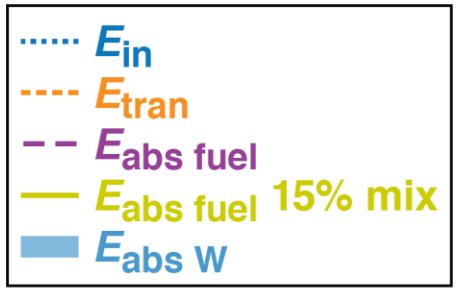
Preheat (J)	B (T)	*P* (atm)	Ti fuel mix (%)	0.2 μm Ti wall layer	Y_{DD}	*HYDRA* T_i (keV)	CR	BR_F/BR_i	$\rho R/\rho R_i$	Bang time (ns)	Beta	Preheat T_i (eV)
90	27	11	0%	No	1.83×10^{10}	3.2	55.12	8.367	17.441	1.655	178	90
70	27	11	0%	No	1.83×10^{10}	3.3	60.59	8.5	15.3114	1.655	128	58
80	35	11	0%	Yes	1.50×10^{10}	3.15	40.25	5.76	7.4	1.67	200	66
80	35	11	0.5%	No	5.43×10^{9}	3.3	72.50	6.8	13.7	1.64	24.4	74
80	35	11	0.5%	Yes	4.58×10^{9}	3.4	66.10	6.79	14.7	1.64	27	72
80	35	11	2.0%	Yes	5.46×10^{7}	2.24	18.48	9.59	9.9	1.54	1.75	65
80	35	11	4.0%	Yes	3.10×10^{7}	2.5	16.80	10.17	9.6	1.54	19.85	56

- The Ti wall layer alone drops the yield by 10% to 15%
- Much larger drops (two orders of magnitude) with large quantity of Ti mixed with fuel

Experimental measurements of preheat pulse transmission were used to model preheat laser deposition in simulations



Past work showed hydrocode modeling of the preheat window disassembly in mini-MagLIF led to lower transmission than experiments



Premixed fuel causes variations in temperature of the core after preheat